The blood runs deep: spatial and temporal distribution, size, and abundance of the blood star (*Henricia spp.)* in the San Juan Channel, Washington, USA.

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Abstract

The San Juan Channel, Washington is home to a diverse seastar community, which includes the blood star (*Henricia spp.*). Few studies have examined the characteristics of the blood star and those have sought to identify morphological difference among species. In this study we examined the spatial and temporal distribution, size, and abundance of the blood star within the San Juan Channel in the San Juan Archipelago. Six locations and 95 transects were established at different depths and using SCUBA, blood stars were photographed and measured. Analysis demonstrated that there was a significant difference in spatial and temporal distributions. Understanding these distributions and investigating the potential factors for the differences is the next step in determining if the causes are natural or anthropogenic.

Key Words: *Henricia spp.*; Blood Star; Spatial; Temporal; Distribution

Introduction

Seastars are among the most ubiquitous animals in the benthos throughout our oceans (Mercier & Hamel 2008) and their habitats have been documented in many parts of the world. Their distributions have been studied both within the intertidal zone and in the deep ocean, but fewer researchers have studied their distribution in the shallow subtidal zone (Himmelman & Dutil 1991). Distribution and abundance may be dictated by the availability of food resources (Gaymer et al. 2001), or by the environmental stressors affecting their habitats (Barahona & Navarrete 2010).

Patterns of distribution among seastars within the intertidal zone have been the focus of several studies; distribution of some seastars has been closely related to their prey, as dictated by their predatory behavior (Paine 1974, Barahona & Navarrete 2010) for example. Other contributing factors to intertidal abundance and distribution of seastars have also been proposed such as sea surface temperature and wave action (Barahona & Navarrete 2010).

Deep-sea distributions of seastars and the factors establishing such distributions have been more extensively studied. Their distributions have been recorded along benthic zones ranging from 30m – 2200m depth (Howell et al. 2002, Ventura & da Costa Fernandes 1995). Of these studies, some determined that a key factor affecting distribution was the subtidal processes that impact the recruitment and juvenile survival of seastars (Himmelman & Dutil 1991), as well as other aspects of their biology (Escolar et al. 2011). Another study determined that key regulating factors were the availability of space and food, as well as intra- and interspecific interactions (Gaymer et al. 2001). Additionally it was suggested that bottom temperature more strongly dictated distribution than other environmental stressors (Franz et al. 1981).

Sea stars of the genus *Henricia* are found along the temperate zones of the Pacific coast from Baja California to British Columbia (Eernisse et al. 2010), as well as locations along the eastern Atlantic coast of the United States (Shield & Witman 1993). *Henricia* species along the Pacific coast have most often been mistakenly consolidated into the single species *Henricia leviuscula* despite many differences in form and function that have been observed (Eernisse et al. 2010). In the Atlantic, *Henricia* is most often found in the rocky subtidal zone (Shield & Witman 1993). Some species of *Henricia* have been described as small brooding seastars (Fisher 1911), while other species, specifically *H. leviuscula*, have been described as free-spawners (Stimpson 1857). The feeding methods of *Henricia* have differed among reports, one reporting they are suspension feeders while others describe them as predators that feed through stomach eversion (Shield & Witman 1993). Differences in breeding mode and prey (marine sponges) may contribute to the broad speciation of *Henricia* in the Pacific. *Henricia's* broad distribution and abundance within the rocky subtidal zone is the primary factor for choosing this genus as the preferred genus of study. Studies have reported on other aspects of *Henricia* behavior, such as the reproductive behavior of some deep-sea species, e.g. *Henricia lisa* (Mercier & Hamel 2009), but very few have reported on their distribution within shallow subtidal zones.

This study examined the spatial and temporal distribution, size, and abundance of the blood star (*Henricia spp.)* within the San Juan Channel in the San Juan Archipelago. Spatially (15 sites and 9 depths) and temporal (6 yrs.) data collected in 2012, and previously collected through photographic quadrats along permanent transects were collated and analyzed. Transects were originally established and data collected as part of a benthic community prey richness and resources use study conducted by Sebens and collaborators (e.g. Elahi & Sebens 2012). The objective of this study was to determine the spatial and temporal distribution of *Henricia* within the San Juan Channel.

Methods

All sites were previously established on subtidal rock walls along islands within the San Juan Channel, Washington, USA. The sites were originally chosen for long-term studies of subtidal community dynamics. The location Shady Cove (San Juan Island; 48°33'08.2" N, 123°00'20.9" W) contains five sites (Figure 1). Locations Mineral Point (San Juan Island; 48°35'36.3" N, 123°04'40.8" W), Pear Point (San Juan Island; 48°31'42.5" N, 122°58'01.4" W), Yellow Island (Yellow Island; 48°35'29.0" N, 123°01'38.2" W), Neck Point (Shaw Island; 48°34'45.1" N, 123°00'45.9" W), and Point George (Shaw Island; 48°33'09.7" N, 122°58'47.9" W) contain two sites apiece (Figure 1). All locations are separated by 2-6 km and are characterized by steep rock walls from 1-10 m in height, intermixed among horizontal and sloping substrata.

To facilitate repeated sampling, each transect was marked at varying depths with a pin mounted to the substrate using marine epoxy. Each of the five Shady Cove sites had permanent horizontal transects established every 3 m from 3 m to 27 m below mean lower low water (MLLW). The remaining sites at Mineral Point, Pear Point, Yellow Island, Neck Point, and Point George also had permanent horizontal transects established but only at every 3m from 9 m to 21 m below MLLW. Quadrats (0.09 m^2) were photographed using SCUBA of all mobile fauna, including *Henricia*, horizontally along each 10 m transect at all depths for each site. Photographs of mobile fauna were taken within 0.5 m (10 m^2) to each side of the original transect line. To facilitate ease and speed of quantifying communities along transects, a second diver counted and measured small mobile fauna to the nearest 1 cm. To prevent overlap, a boundary was established between the diver photographing small mobile fauna and the diver conducting measurements. Photographs and measurements were then analyzed at the lab.

When quantifying the number of animals within each transect a simple count was conducted. *Henricia* length was measured as the summed distance from the tip of the two longest arms to the center of the disc. All transects were surveyed annually between October and January. For this study data collected from 2007 to 2012 was used to examine the temporal and spatial distribution, size, and abundance of the blood star (*Henricia spp.*) within the San Juan Channel.

After data collection, all measurements were entered into an excel spreadsheet. The spreadsheet was then loaded into R version 3.0.2 for statistical analysis. A general linear model was used for analysis and an ANOVA was run on both abundance and size to determine if a significant difference existed among the three factors (depth, size, and site) and if there was a correlation between factors. The null hypothesis was that there were no difference spatially or temporally among depths, year, and sites within the San Juan Channel.

Results

The blood star *Henricia spp.* was present at all 15 study sites within the San Juan Channel. The greatest abundance of *Henricia* on a single transect was 14 seastars (1.4 ind m^{-2}) at the 24 m depth at Shady Cove, Madrona Tree in 2007. Average abundance at different depths ranged from 1.0 per transect at 9 m to 4.2 per transect at 24 m, with a trend that population density generally increased as depth increased (Figure 2). At 27m there is a drop in the average abundance to 3.3 per transect (Figure 2). Average annual abundance from 2006 to 2012 ranges from 1.3 per transect in 2006 to 2.5 per transect in 2011, with a trend that generally increased with each year (Figure 3). The range of average abundance for locations was 1.1 per transect at Mineral Point to 2.9 per transect at Neck Point (Figure 4). The most northern locations, Mineral Point (1.1 per transect) and Yellow Island (1.2 per transect), presented the lowest average abundance of all locations, while Neck point (2.9 per transect) presented the greatest average abundance (Figure 4). According to the GLM a significant difference ($p << 0.001$) existed in the average abundance among depth, year, and site. It also showed a significant difference in the interaction between year:site ($p = 0.004$), depth:site ($p << 0.001$), and year:depth:site ($p << 0.001$). The interaction between year:depth ($p = 0.687$) was not significant and showed no influence on the abundance of *Henricia*.

The greatest average size of *Henricia* per transect was 16.5 (n = 2) at the 18 m depth at Pear Point, Minnesota Reef in 2012. Average size at different depths ranged from 7.7 cm per transect at 9 m to 9.4 cm per transect at 27 m, with a trend that generally increased as depth increased (Figure 5). Average annual size from 2006 to 2012 it ranges from 8.0 per transect in 2006 to 9.2 per transect in 2007 (Figure 6). Though the largest average size was observed in 2007 and the trend appears to decrease to 8.6 in 2012, the average size actually increased (slope = 0.054) over the six-year period, but was not significant. The mid-channel location, Neck Point (7.1 cm), presented the least average size of all locations, while Pear Point (9.9 cm) and Yellow Island (9.8 cm) presented the greatest average size (Figure 7). According to the GLM a significant difference existed in the average size among depth ($p = 0.002$) and site ($p << 0.001$), but not year. It also presented a significant difference in the interaction between year:site ($p < 0.001$) and depth:site ($p = 0.056$). Year ($p = 0.408$) was not significant and presented no influence on the size of *Henricia*. Also, the interaction between year:depth ($p = 0.317$) and year:depth:site ($p = 0.786$) was not significant.

Discussion

In this study we found a difference in the distribution, size and abundance of blood stars (*Henricia spp.)* both spatially and temporally within the San Juan Channel, Washington, USA. Based on the abundance data, *Henricia* generally preferred subtidal depths beyond 15m and this is where we observed the greatest number of seastars for all study locations. Also, the greatest numbers were discovered in the mid-channel locations. Temporally, *Henricia* increased in abundance during the six study years. Considering the size data, we observed that the largest of the *Henricia* generally occupied greater depths and those locations closer to the north and south ends of the channel. Temporally, the average size of the *Henricia* increased with each study year, but was not significant. There is thus the possibility that there are certain habitat factors that might influence the preferred habitat of these seastars.

When studying the abundance of *Henricia spp.* we demonstrated that there was a strong influence of depth over the number of seastars observed per transect. A four-fold increase in the average abundance was observed from 6 m depth down to 24 m. There are several factors within the marine environment that potentially change with the increase in depth, such as temperature, salinity, and predator/prey interactions. Which of these factors influence the abundance would be hard to say without further research. However, in other studies temperature has demonstrated an effect on the survival, reproduction, and development of juveniles of other seastars (Franz et al. 1981). Of course, temperature would not necessarily present the same effects on *Henricia* as observed in the other seastars. Within the San Juan Channel there are large freshwater inputs from the Fraser River and other rivers in the area, which could potentially affect depth distribution. Echinoderms are described as a stenohaline phylum and there exists a strong correlation between increased salinity and vertical distribution of seastars (Barker & Russell 2008). Biotic interactions, specifically predator/prey, have also been observed as a significant factor which influences depth distribution of other seastars (Franz et al. 1981, Gaymer et al. 2001). To determine the prey relationship and its effect on depth distribution of *Henricia* further studies are necessary to determine the temporal and spatial distribution of the sponges upon which they feed.

The analysis of abundance presented an increase temporally over the course of the seven years for which the data was collected. This trend is what would be expected if in previous years the number of *Henricia* made it to reproductive age and produced offspring. Further analysis of recruitment and juvenile survival would be necessary to determine the number of individuals that make it to reproductive age. *H. leviuscula,* commonly identified as the species within the San Juan Channel has been described as a free-spawning species and though larvae survival and recruitment of this reproductive style are low it can be assumed that some will survive to reproductive age.

The analysis then demonstrated there was a relationship between the average sizes of *Henricia* and its spatial distribution among the recorded depths. Average size increased from 7.7 cm at 9 m in depth to the largest average size of 9.4 cm at 27 m in depth. Some potential factors leading to such a distribution could be the abundance of prey, a reduction in competition, temperature, or salinity. Abundance of prey and less competition for food sources would provide the seastars with the necessary and easily available nutrients to increase body mass, growing larger. If temperature or salinity in the shallow zone were stressful to this seastar, then energetic costs could be higher and growth rates lower in this zone.

Finally, when observing the distribution, size, and abundance at each location it was determined that the greatest numbers of *Henricia* were located at the mid-channel locations at Neck Point and Shady Cove. However, the largest individuals were located at the two locations (Yellow Island and Pear Point) near the north and south entrance into the San Juan Channel. Some factors that could potentially account for this type of distribution are direction of the subtidal rock face, maximum depth at that location, and the flow of current.

Ultimately this study presents data that rejects the null hypothesis that there are no significant differences among depths, years, or sites for these seastars. A significant difference exists spatially, but it was also observed that a significant difference exists temporally. There could potentially be some important factors that are responsible for the observed spatial and temporal distribution, abundance, and size of *Henricia*. Further studies are necessary to identify these potential factors of temperature, salinity, prey abundance, and what their significance may be for the future survival of *Henricia* or other subtidal communities.

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Figures

Figure 1. Google Earth map depicting the six locations where permanent horizontal transects were established within the San Juan Channel.

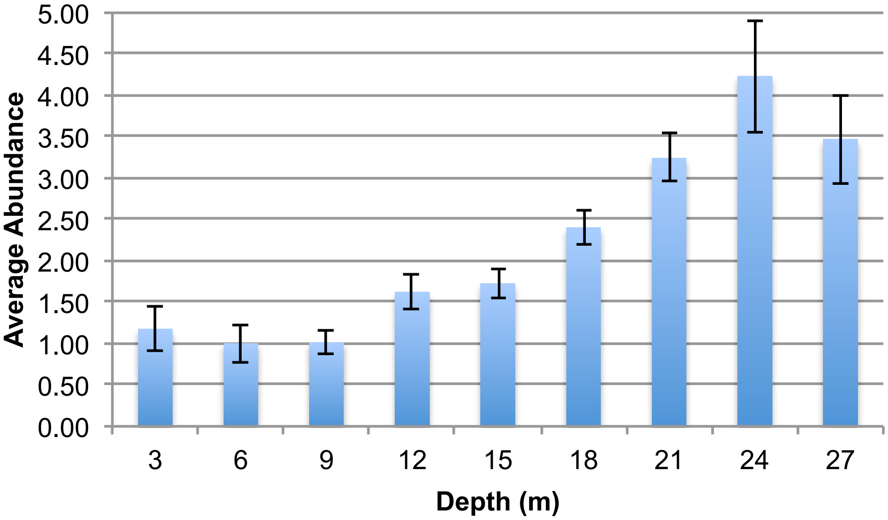

Figure 2. The average abundance and standard error of *Henricia spp.* among depths 3-27m (3m increments) for all six locations within the San Juan Channel for the years 2006 through 2012. The number of *Henricia* for each site were counted at each depth during each year, then averaged for each depth.

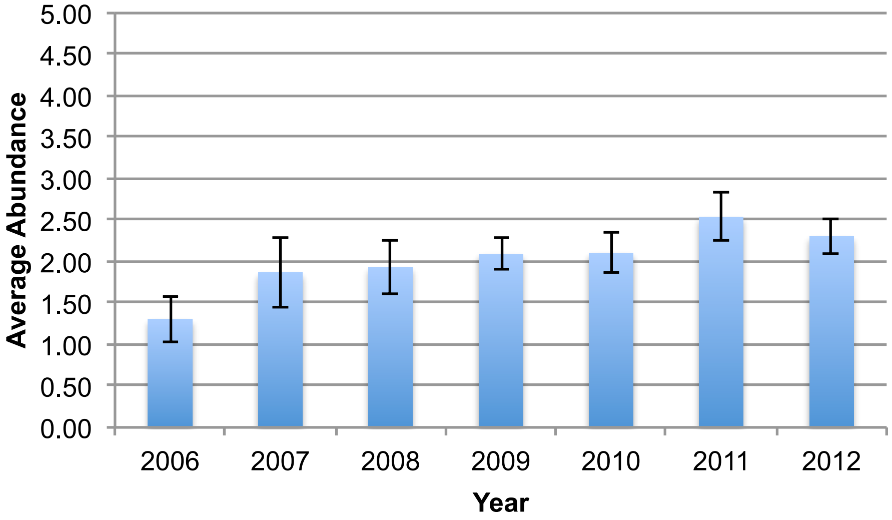

Figure 3. The average abundance and standard error of *Henricia spp.* among the years 2006 through 2012 for all six locations and depths within the San Juan Channel. The number of *Henricia* for each site were counted at each depth during each year, then averaged for each year.

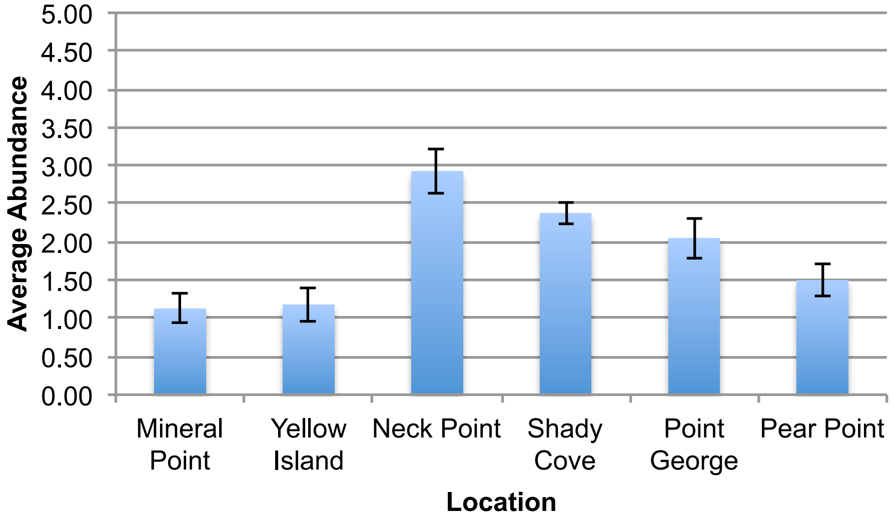

Figure 4. The average abundance and standard error of *Henricia spp.* among the six locations for all years and depths within the San Juan Channel. The number of *Henricia* for each site were counted at each depth during each year, then averaged for each location.

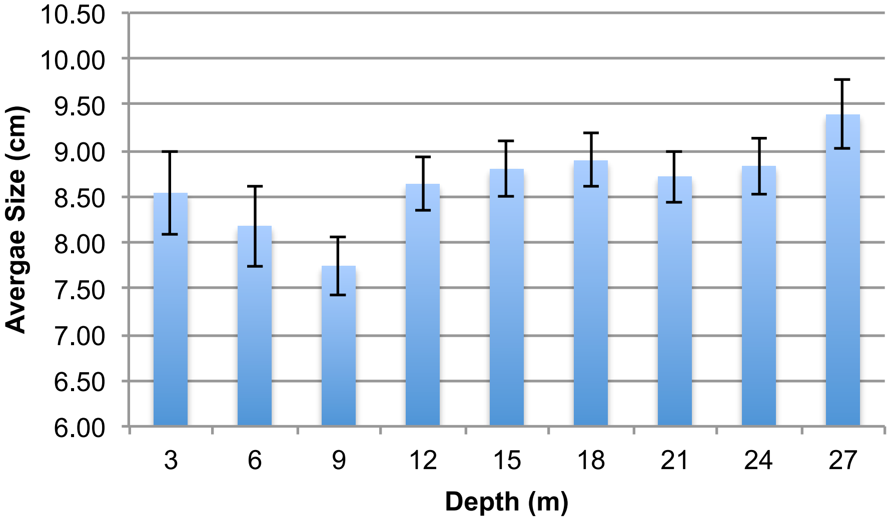

Figure 5. The average size and standard error of *Henricia spp.* among depths 3-27m (3m increments) for all six locations within the San Juan Channel for the years 2006 through 2012. The size of each *Henricia* was determined by measuring the length of the two longest arms (nearest cm), then adding the two lengths for total size. The total size for each *Henricia* was calculated for each site, year, and depth, then averaged for each depth.

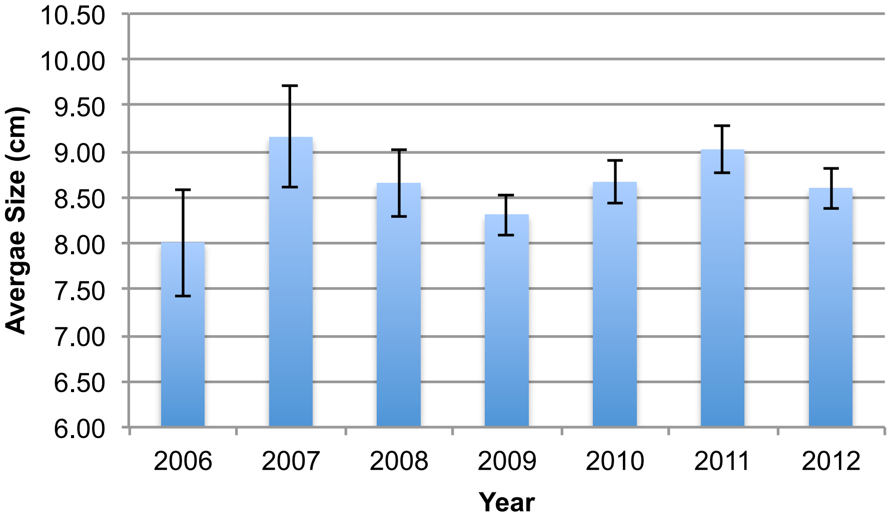

Figure 6. The average size and standard error of *Henricia spp.* among the years 2006 through 2012 for all six locations and depths within the San Juan Channel. The size of each *Henricia* was determined by measuring the length of the two longest arms (nearest cm), then adding the two lengths for total size. The total size for each *Henricia* was calculated for each site, year, and depth, then averaged for each year.

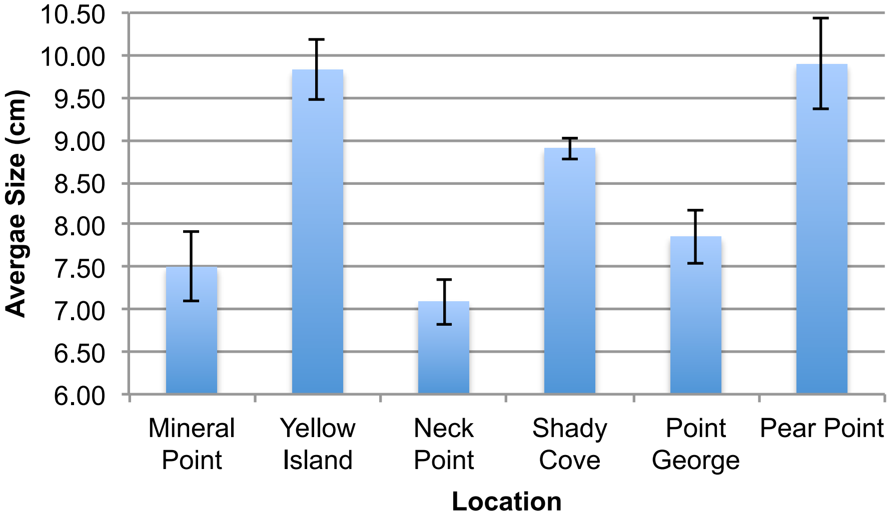

Figure 7. The average size and standard error of *Henricia spp.* among the six locations for all years and depths within the San Juan Channel. The size of each *Henricia* was determined by measuring the length of the two longest arms (nearest cm), then adding the two lengths for total size. The total size for each *Henricia* was calculated for each site, year, and depth, then averaged for each locations.

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